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Potential Mechanisms of the Alexander Technique: Toward a Comprehensive Neurophysiological Model

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The Alexander technique (AT) has been practiced for over 125 years. Despite evidence of its clinical utility, a clear explanation of how AT works is lacking, as the foundational science needed to test the underlying ideas has only recently become available. The authors propose that the core changes brought about by Alexander training are improvements in the adaptivity and distribution of postural tone, along with changes in body schema, and that these changes underlie many of the reported benefits. They suggest that AT alters tone and body schema via spatial attention and executive processes, which in turn affect low-level motor elements. To engage these pathways, AT strategically engages attention, intention, and inhibition, along with haptic communication. The uniqueness of the approach comes from the way these elements are woven together. Evidence for the contribution of these elements is discussed, drawing on direct studies of AT and other relevant modern scientific literature.

***Keywords*:** body axis, body schema, muscle tone, musculoskeletal pain, postural tone, somatic practice

Evidence is mounting that practicing the Alexander technique (AT) has a range of benefits. Clinical research suggests that it can help alleviate common musculoskeletal complaints such as chronic back, neck, and knee pain (Little et al., 2008; MacPherson et al., 2015; Preece, Jones, Brown, Cacciatore, & Jones, 2016). AT may improve responses to stress (Glover, Kinsey, Clappison, & Jomeen, 2018; Gross, Cohen, Ravichandra, & Basye, 2019; Gross, Ravichandra, & Cohen, 2019; Klein, Bayard, & Wolf, 2014; Valentine, Fitzgerald, Gorton, Hudson, & Symonds, 1995; Zhukov, 2019) while also improving motor performance on tasks as specialized as playing a musical instrument or as basic as standing, walking, and breathing (Austin & Ausubel, 1992; Cacciatore, Gurfinkel, Horak, & Day, 2011; Cacciatore, Mian, Peters, & Day, 2014; Cohen et al., 2020; Cohen, Gurfinkel, Kwak, Warden, & Horak, 2015; Hamel, Ross, Schultz, O'Neill, & Anderson, 2016; O'Neill, Anderson, Allen, Ross, & Hamel, 2015). See Woodman and Moore (2012) for a fairly recent clinical review. Until now, however, a comprehensive explanation for the mechanisms by which AT operates has been lacking (Woodman & Moore, 2012).

Because of its century-long history, AT suffered scientifically from being "ahead of its time." Initial investigations into possible mechanisms of AT had to rely on sparse scientific literature (see Barlow, 1946; Jones, Hanson, Miller, & Bossom, 1963) that referenced reflex models of posture that are now known to be out of date (Davidoff, 1992). In addition, the comprehensive and multifaceted nature of AT does not lend itself to simple experimental designs, and the foundational science and technology needed to test the underlying ideas have only recently become available.

In recent decades, our collective understanding of neuroscience and psychology has progressed immensely, such that there are now solid bodies of research in which to ground our theories and research. In the last 15 years, some reports addressing possible mechanisms of AT have been published (Becker, Copeland, Botterbusch, & Cohen, 2018; Cacciatore, Gurfinkel, Horak, Cordo, & Ames, 2011; Cacciatore, Gurfinkel, Horak, & Day, 2011; Cacciatore et al., 2014; Cohen et al., 2015, 2020; Hamel et al., 2016; Loram, 2013; O'Neill et al., 2015), while other research has elaborated on concepts relevant to AT's function.

In this paper, we propose a comprehensive model of the underlying mechanisms of AT. Based on published evidence, we posit that mental phenomena such as intention and spatial attention influence postural tone, the background muscle activity that stabilizes body configuration—and that these changes in postural tone in turn affect many aspects of the motor system. We further posit that broader research on interconnections between postural tone and body schema may help explain changes in body-based self-perception through AT training. Although AT affects pain and is likely to affect mood, our model suggests that those effects are downstream from (or at least interdependent with) changes in the motor system.

A key purpose of our model is to explain AT's generalizability, meaning that something learned in one task carries over to other activities. By explicating the role of postural tone in motor activity, we can start to understand how AT can have such a wide range of effects.

What Is AT?

The most common reasons that people study AT are to overcome problems with chronic musculoskeletal pain and to improve posture, general well-being, or skilled performance (Eldred, Hopton, Donnison, Woodman, & MacPherson, 2015). AT is usually taught either in one-to-one sessions or small group classes. Activities in sessions often include basic actions such as standing and sitting, as well as more complex actions such as speaking, singing, walking, running, and writing. Alexander teachers use verbal and manual guidance to assist in improving postural coordination, kinesthetic perception, and functionality in everyday activity.

A distinguishing feature of AT is that sessions do not focus on perfecting particular movements, practicing balance tasks, or

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imposing a specific postural alignment. AT differs markedly from popular approaches to posture that emphasize effortfully lifting the head, straightening the back, squeezing together the shoulder blades, and tensing the abdominal muscles (American Chiropractic Association, n.d.; Harvard Medical School, n.d.; Medline Plus, 2020; National Osteoporosis Foundation, 2018; Peeke, 2015). Instead, pupils learning AT practice noticing and altering counterproductive muscle tensions and automatic reactions that occur at rest, in anticipation of action, and during movement. The practice of attending to posture and reaction before and during activity is thought to lead to global improvement in motor behavior, reduction in anxiety and pain, and increased self-efficacy. While AT concerns itself with improving the accuracy of body-based self-perception, a focus of training is on *not* micromanaging the details of coordination. AT posits that "nondoing" attention and intention on certain areas of the body—for example, the head–neck region—can have cascading benefits throughout the neuromuscular system.

AT's Reported Effects on Movement and Balance

AT has been shown to affect at least two major categories of motor action: movement and balance. We will discuss the proposed mechanisms for AT's generalizability after briefly reviewing evidence for its broad motor effects.

Movement

Evidence that AT affects movement comes from four different motor domains: rising from a chair, walking, breathing, and movement preparation.

Rising From a Chair. Alexander teachers traditionally include work with students rising from a chair, with some teachers incorporating the activity extensively into their lessons. Studies have found that a major effect of Alexander training on rising from a chair occurs during the forward weight shift (Figure 1). Alexander-trained participants demonstrate a smooth weight transfer consisting of a gradual increase in foot force and a relatively uniform forward velocity, while control participants abruptly increase foot force and forward velocity at seat-off, suggesting a reliance on forward momentum (Cacciatore et al., 2014). These results were consistent across a range of movement durations, from faster than normal (1 s) to unusually slow (8 s). Controls were unable to mimic the smooth weight transition of teachers even when instructed and provided with performance feedback. Controls also demonstrated changes in spinal alignment during weight shift that were not present in Alexander-trained individuals (Figure 2), who maintained a near-isometric spine (Cacciatore, Gurfinkel, Horak, & Day, 2011).

Walking. Three studies have examined the effects of AT on gait. One found that after Alexander lessons, patients with knee osteoarthritis had decreased knee cocontraction while walking (Preece et al., 2016) that correlated with decreased pain. Another study found reduced mediolateral center-of-mass displacement in older Alexander teachers compared with age-matched controls during fast-paced walking, as well as significantly smaller stride width and lower gait-timing variability (O'Neill et al., 2015). A third study found reduced trunk and head motion but increased ankle-joint motion in older Alexander teachers than in age-matched controls during the stance phase of gait (Hamel et al., 2016). During the swing phase, Alexander teachers displayed greater hip and knee flexion than controls, more like the coordination of younger subjects.

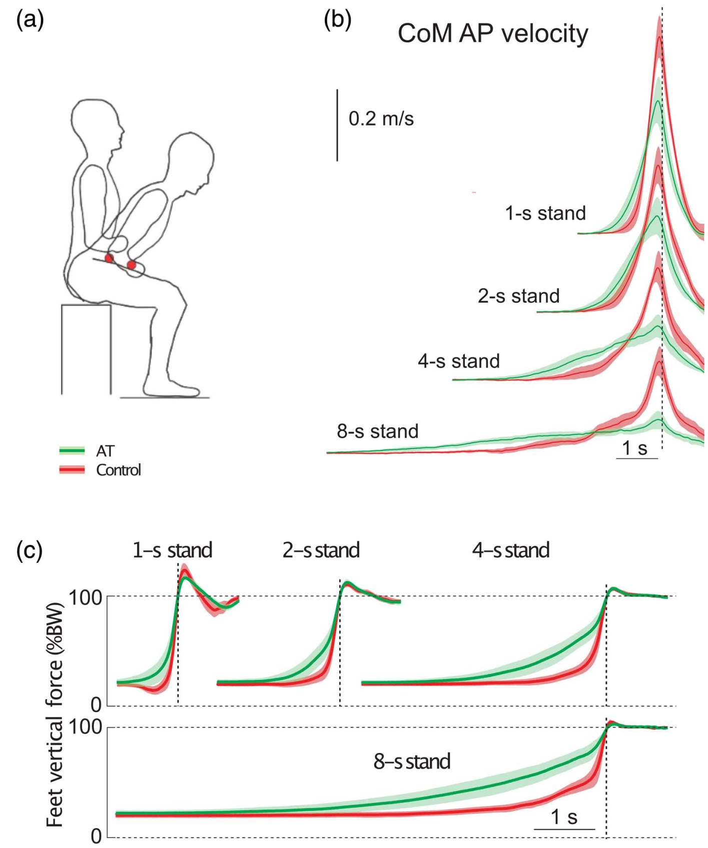

Figure 1 — Coordination of sit-to-stand in teachers of the Alexander technique (AT) and controls. (A) Subjects (10 AT, 10 controls) were asked to stand up as smoothly as possible at a uniform speed from a standardized chair position. Note that the feet were far forward (shank angle was at 10°), making it quite difficult to rise slowly and smoothly. (B) Forward (anteroposterior; AP) center-of-mass (CoM) velocity across four movement durations (1 s, 2 s, 4 s, 8 s). Mean and 95% confidence interval are shown for each group and condition, aligned to the time of seat-off (vertical dashed line). Movement durations did not differ between groups. Control subjects were unable to prevent the abrupt increase in forward velocity for the two slower conditions and in general used a higher peak velocity for the same movement duration. Alexander teachers were able to perform a slow, smooth chair rise with a relatively uniform forward velocity. (C) Vertical force under the feet. Group means and confidence intervals are shown. Vertical dashed lines are seat-off. Alexander teachers had an early and gradual rise in underfoot force, while control subjects had an abrupt rise just before seat-off across all movement durations. Adapted from *Journal of Neurophysiology, 112*(3), Cacciatore, T.W., Mian, O.S., Peters, A., & Day, B.L., Neuromechanical interference of posture on movement: Evidence from Alexander technique teachers rising from a chair, 719–729, Copyright 2014, American Physiological Society, Creative Commons.

Breathing. AT is often used to improve breathing. This is reflected in the prevalence of Alexander training in music and theater departments (including such prestigious conservatories as the Juilliard School, the Royal Academy of Music, and Yale School of Drama), in many anecdotal reports (Heirich, 2011), and in several case studies (Bosch, 1997; Kaplan, 1994; Lloyd, 1986). In addition, a controlled study found improvements in several

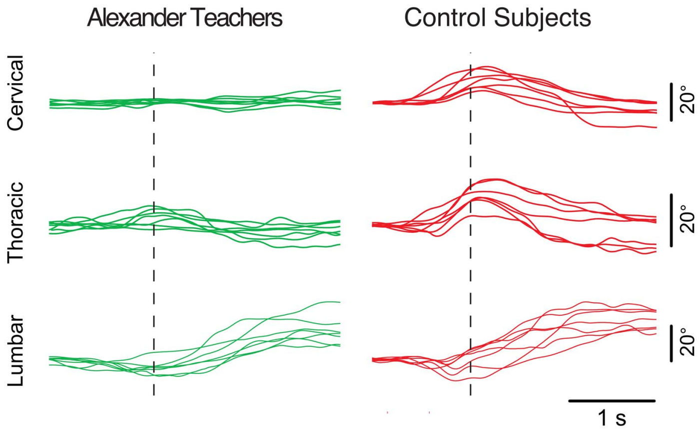

Figure 2 — Spinal angles at three different levels for Alexander teachers and control subjects during a chair rise. Each trace represents data from an individual subject. Alexander teachers had far less spinal movement than control subjects in their necks (cervical), upper torsos (thoracic), and lumbar region. Note that movement occurred during the period of changing spinal forces around seat-off. Thoracic and lumbar angles are calculated as in Figure 5. Adapted from *Gait & Posture, 34*(4), Cacciatore, T.W., Gurfinkel, V.S., Horak, F.B., & Day, B.L., Prolonged weight-shift and altered spinal coordination during sit-to-stand in practitioners of the Alexander technique, 496–501, Copyright 2011, with permission from Elsevier.

breathing measures after a series of 20 AT lessons, while improvements did not occur in the control group. Notably, AT-related improvements in maximal expiratory pressure, maximum inspiratory pressure, and peak expiratory flow occurred without practicing specific breathing exercises (Austin & Ausubel, 1992). In contrast, a study of musicians did not find improvements in peak flow rates after 15 lessons, although improvements in heart rate, self-reported anxiety, and musical and technical performance were found (Valentine et al., 1995). The different result in the latter study may be because of the musicians' prior training (Klein et al., 2014).

Movement Preparation. Two studies demonstrated improvement in movement preparation after instructions similar to those used in Alexander lessons. Loram, Bate, Harding, Cunningham, and Loram (2016) demonstrated that intentionally reducing activity in surface neck muscles while playing the violin led to beneficial cascading effects throughout the musculoskeletal system. When subjects used visual biofeedback to reduce neck-muscle activity, leg-muscle activity and galvanic skin response decreased without hindering performance. Another study found that AT-based instructions to think of effortlessly upright posture led to better control of step initiation, with a smoother center-of-pressure trajectory, than either a relaxed posture or an effortful "core strength" approach (Cohen et al., 2015). In addition, the AT-based instruction seemed to improve the efficiency of the anticipatory postural adjustment, as participants decreased lateral motion of the center of pressure without affecting its backward movement during push-off.

Balance

A number of studies have found improvements in balance after AT instruction. Functional reach increased after AT lessons in a controlled study of older adults (Dennis, 1999), and preliminary work suggests that AT classes also improve standard clinical balance measures in people with Parkinson's disease (Gross, Ravichandra, & Cohen, 2019). In addition, two studies using AT-inspired instructions found reductions in postural sway during quiet stance and brief single-leg stance (Figure 3; Cohen et al., 2015, 2020). Finally, a single-subject case study found that a course of AT lessons led to improvements in automatic balance reactions (Cacciatore, Horak, & Henry, 2005).

Postural Tone and the Generalizability of AT

We propose that the range of beneficial long-term outcomes of AT study and practice are caused by improvements in the adaptivity and distribution of postural tone, along with concomitant changes in body schema. We elaborate on this idea below.

Postural Tone

Postural muscle tone, also known simply as postural tone, is the steady yet adaptable background muscle activity necessary for opposing gravity, stabilizing body configuration, and organizing coordinated movement (Gurfinkel et al., 2006; Ivanenko & Gurfinkel, 2018). Historically, it has been difficult to study due to its small magnitude and broad distribution throughout the body (Gurfinkel, 2009). Postural tone is generated subconsciously and differs from voluntarily holding a posture, like clenching a fist or "standing up straight" (St George, Gurfinkel, Kraakevik, Nutt, & Horak, 2018). Tone must also be adaptable to resist forces such as those from stretched tissues or gravity and to comply with forces to allow desired movement and accommodate different postures.

Axial postural tone (in the neck and torso) is especially important, as the spine is central and connects the limbs to the torso. Thus, stabilizing the axis is key for mediating interactions between limbs and for coordinating the limbs and torso into a functioning unit (Gurfinkel et al., 2006). Because the spine is made up of separate vertebrae, it is inherently unstable and must be stabilized by postural tone (Lucas & Bresler, 1960). This stabilization process is complex and redundant—one can stabilize the spine with different combinations or distributions of muscle actions: deep versus surface, medial versus lateral, and so on (Gurfinkel et al., 2006; Moseley, Hodges, & Gandevia, 2003). Crucially, tone needs to be regulated in a way that stabilizes the torso while also allowing for mobility (Ivanenko & Gurfinkel, 2018).

Postural tone must be orchestrated across body regions. Multiarticular muscles, which cross multiple joints, are prominent in the body, especially in the body axis. When a muscle that crosses multiple joints exerts force, that force cannot simply be counteracted locally by cocontracting (as is the case, for instance, with a single flexor vs. a single extensor). Instead, unbalanced tension in a multiarticular muscle may cause tension to spread across the body (Loram et al., 2016). Such a spreading mechanism could cause spinal stiffness from poor axial support to lead to stiffness in more distal joints, interfering with breathing, balance, and mobility.

AT Affects Postural Tone. We propose that Alexander training changes the distribution of postural tone and makes tone more adaptive. Consequently, a person can be compliant or resistant to external forces as appropriate to the situation.

Several studies suggest that AT changes the distribution of tone. Notably, AT seems to shift axial muscle activity from superficial to deeper muscles. This was first demonstrated by asking participants to sit in three ways: with their usual posture, with "greatest height," and with Alexander guidance.

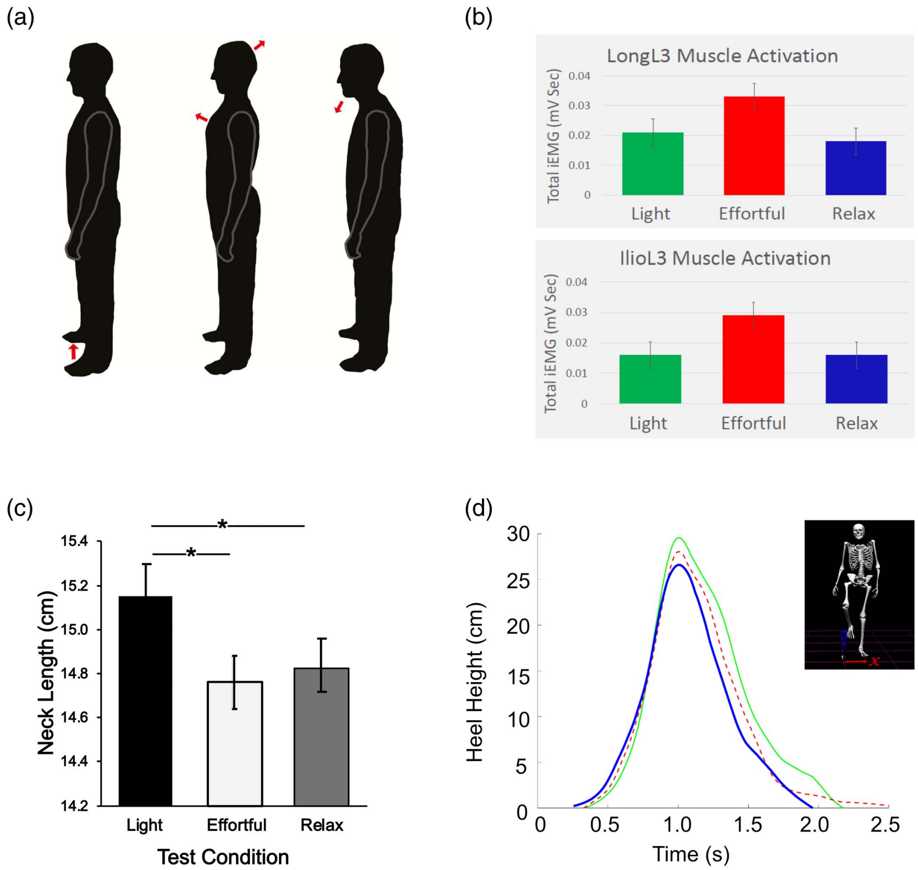

Figure 3 — Effect of brief postural instructions on motor outcomes. (A) Schematic of light, effortful, and relaxed instructed postures used in two counterbalanced within-subject studies. From Cohen et al. (2020). (B) Total integrated muscle activity from longissimus and iliocostalis muscles at the level of the third lumbar vertebra was higher in the effortful condition than in light or relaxed conditions in 19 healthy older adults. Group means and standard-error bars are shown. Adapted from Cohen et al. (2020). (C) Linear distance between shoulder and ear, determined from reflective markers, was greater in the light condition than in the effortful or relaxed condition in 20 older adults with Parkinson's disease, indicating a more lengthened stature. Group means and standard-error bars are shown. Adapted from Cohen et al. (2015). (D) Nineteen healthy older adults were instructed to raise their left foot and hold it up for 3 s. In the light condition (the top line in the plot) they came closest to achieving this goal. Group means are shown. Adapted from *Innovation in Aging,* Cohen, R.G., Baer, J.L., Lighten up! Postural instructions affect static and dynamic balance in healthy older adults, Copyright 2020, Oxford University Press, Creative Commons.

The Alexander guidance reduced superficial neck-muscle activity compared with the other two conditions (Jones, Hanson, & Gray, 1961). More recent evidence comes from a study of people with neck pain (Figure 4), in which surface neck-muscle activity decreased during a neck-flexion task after 10 group AT classes (Becker et al., 2018). While either of these findings could indicate an overall reduction in muscle activity, other work has shown a tendency for activity in deep and superficial neck muscles to be negatively correlated, suggesting a shift in distribution of tone (Jull, Falla, Vicenzino, & Hodges, 2009). At first glance, it seems inefficient to activate deeper muscles, which have smaller moment arms and are thus less powerful than superficial ones. However, the deeper axial muscles such as semispinalis and deep multifidus may allow for more precise control of position and movement as they are shorter in range and cross fewer joints than superficial muscles such as the sternocleidomastoid and trapezius. When considered collectively, the shorter-range muscles have more degrees of freedom than the more superficial muscles (Moseley et al., 2003).

Evidence that AT changes tone distribution also comes indirectly from observed changes in postural alignment. Unpublished data show that Alexander teachers have reduced spinal curvature during quiet stance compared with age-matched controls (Figure 5). Crucially, changes in postural alignment are typically not directly instructed or manipulated in Alexander training and therefore most likely result from a change in postural tone rather than voluntarily adopting a position (Cacciatore et al., 2005).

To facilitate both stability and mobility, postural tone must adapt to, comply with, or resist depending on the circumstance. Three studies found that Alexander training improves compliance in the body axis. This evidence was obtained via Twister, a device that assesses postural tone in standing participants (Gurfinkel et al., 2006). The device measures resistance to very slow twisting of axial body regions. The measured resistance reflects the postural tone of all muscles that cross the twisted region. As the device does not provide support, tone is required to remain upright. Thus, the device measures postural tone and not stretch reflexes or voluntary action. Alexander teachers were found to have half the neck, trunk, and hip stiffness of matched controls (Figure 6; Cacciatore, Gurfinkel, Horak, Cordo, & Ames, 2011). Increased compliance was also found in the trunk and hips after a course of 20 AT lessons compared with a control intervention, after remaining stable during a preintervention baseline period (Cacciatore, Gurfinkel, Horak, Cordo, & Ames, 2011). Another study found increased trunk compliance after brief AT-based

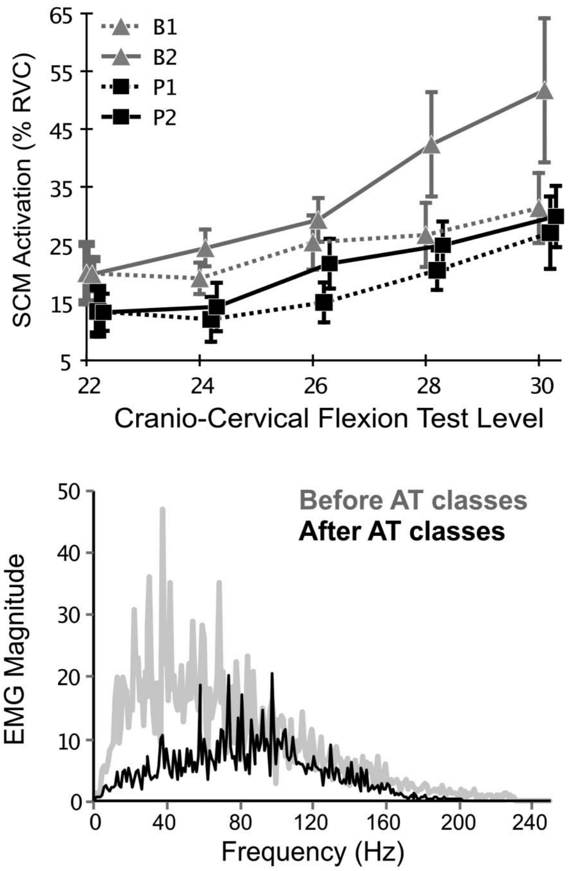

Figure 4 — Surface neck-muscle activity was altered after a series of 10 Alexander technique (AT) classes in 10 adults with chronic neck pain. Adapted from Becker et al. (2018). The top figure shows peak sternocleidomastoid (SCM) activation as a percentage of reference voluntary contraction (10-s supine head raise) at the five standardized neck-flexion levels of the craniocervical-flexion test. Testing sessions were 5 weeks apart. Relative muscle activation was higher in the two baseline sessions (B1, B2) than in the two postintervention sessions (P1, P2). Group means and standard errors are shown. The lower figure shows a power spectrum of SCM activation during two trials from the same subject at the same flexion level before and after classes. The biggest difference was a decrease in low-frequency activity after classes, suggesting a decrease in muscle fatigue. Adapted from *Complementary Therapies in Medicine, 39,* Becker, J.J., Copeland, S.L., Botterbusch, E.L., & Cohen, R.G., Preliminary evidence for feasibility, efficacy, and mechanisms of Alexander technique group classes for chronic neck pain, 80–86, Copyright 2018, with permission from Elsevier.

instructions compared with other postural instructions (Cohen et al., 2015). Increases in axial compliance reflect increased adaptivity of tone (Cacciatore, Gurfinkel, Horak, Cordo, & Ames, 2011; Gurfinkel et al., 2006).

Several observations suggest that AT improves the ability to accurately counteract imposed forces to maintain an intended position. Many activities common in Alexander lessons involve matching forces in a postural context. This appears to be achieved dynamically rather than by stiffening via cocontraction. Figure 7 shows the ability of a seated AT teacher to precisely counteract unpredictable forces on the back, transmitting these forces through the feet to the ground and remaining stationary. The control subject was not able to precisely match the forces.

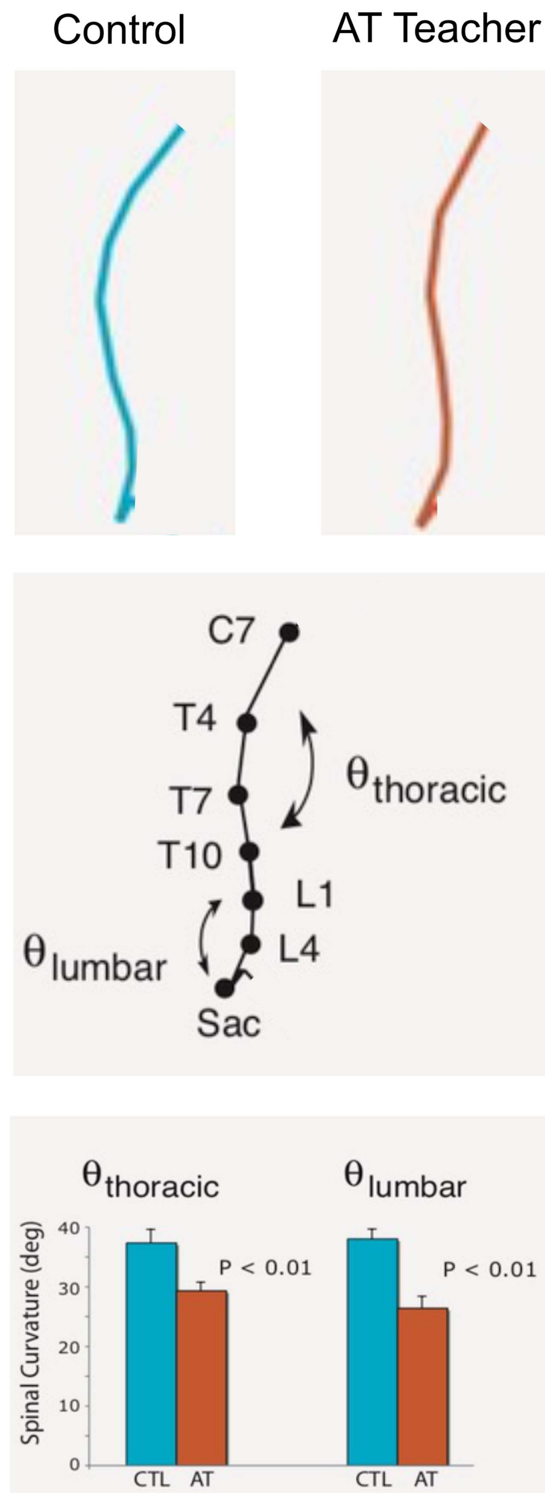

Figure 5 — Sagittal-spine curvature in Alexander teachers and age-matched control subjects during quiet stance. Subjects were unaware of what was being assessed. Unpublished data from Cacciatore and Horak collected at Oregon Health and Science University. (Top) Back curvature in a representative control subject and Alexander teacher. (Middle) Placement of motion-capture markers. (Bottom) Mean and standard error of spinal curvature of 14 controls and 15 Alexander teachers, defined as the sums of the three thoracic angles and two lumbar angles shown in the middle panel. Alexander teachers had lower thoracic and lumbar curvature than controls, indicating a redistribution of postural tone.

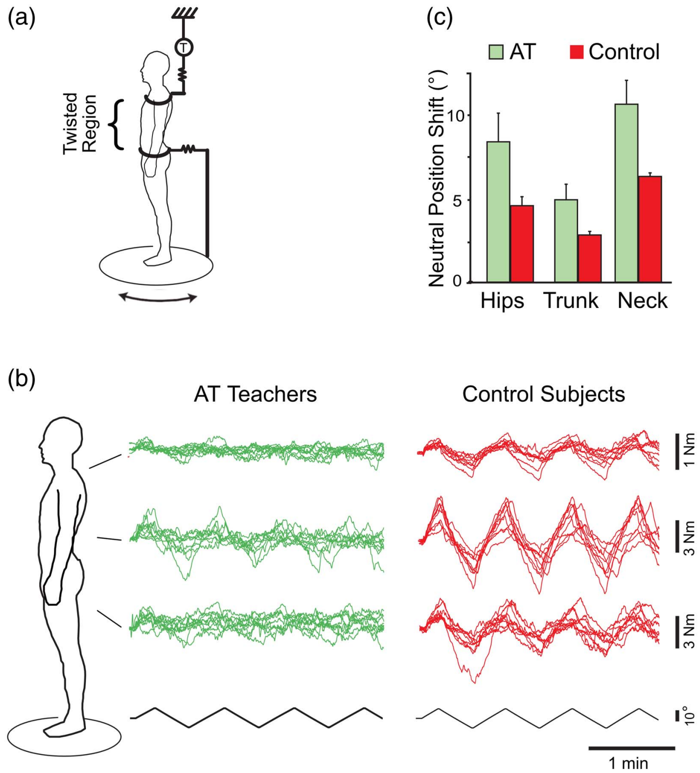

Figure 6 — Axial postural tone in Alexander teachers and age-matched control subjects. (A) Diagram of Twister device used to measure postural tone. Shown in the configuration for twisting the trunk between the shoulders and the pelvis. Very slow rotation of the platform (±10°, 1°/s) caused twisting. Hinges ensured that only torsion was stabilized so that postural support was necessary. A torque sensor measured resistance to twisting. (B) Resistance to twisting of the neck, trunk, and hips for 15 controls and 14 Alexander teachers. The bottom trace indicates platform rotation. Each trace represents torque data from a single subject across a multiminute trial in which the region was twisted back and forth several times. Alexander teachers had substantially lower resistance across all three axial levels, as indicated by the flatter torque traces. (C) Shift in neutral position during twisting, calculated from the shape of the resistance trace. At all three levels, Alexander teachers had a greater shift in neutral position, indicating more adaptable postural tone that yielded to the imposed motion. Group means and standard error are shown. In AT teachers the neutral position of the neck and hips adapted nearly the full magnitude (10°) of the imposed twisting. Adapted from *Human Movement Science, 30*(1), Cacciatore, T.W., Gurfinkel, V.S., Horak, F.B., Cordo, P.J., & Ames, K.E., Increased dynamic regulation of postural tone through Alexander technique training, 74–89. Copyright 2011, with permission from Elsevier.

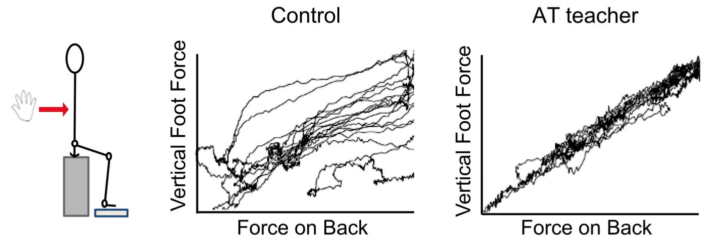

Figure 7 — Resistive response to unpredictable loading applied to subjects' backs. Unpublished data from Cacciatore and Day, collected at the Institute of Neurology, University College London. Loading was applied with a force transducer as subjects sat with their feet on a force platform and were instructed to not let their torsos move. The data for Alexander teachers (*n* = 2) show a strong correlation between underfoot force and back force, indicating a precise resistive response that closely matched applied loading. In contrast, the data for control subjects (*n* = 2) show a much more variable relationship between back force and underfoot force, indicating a delayed and less precise stabilization to loading. Peak forces were approximately 50 N. AT = Alexander technique.

Perhaps the most common example of force matching in AT is in rising from a chair. Up through weight shift, rising from a chair can be treated as a matching task, where gravity acts to incline the trunk and also flex the knee and ankle by translating the femur forward. Closely opposing these flexor torques with hip, knee, and back extensors weights the feet smoothly (analogous to the situation in Figure 7) and produces a quasistatic action, so that the movement can be performed without relying on momentum. To perform this task well, one must activate extensor muscles to match the sensory input while preventing excess tension that hinders forward progression of the body mass over the feet. Alexander teachers may impart this skill in a lesson by applying forces to a pupil's back or neck and varying the movement trajectory unpredictably so that the pupil cannot preplan a trajectory and must rely on a matching strategy.

Other observations support the hypothesis that AT improves force matching. The reduced mediolateral center-of-mass displacement in AT teachers' gait is consistent with better matching of contact forces from the ground up through the kinematic chain of body segments (O'Neill et al., 2015). Reduced mediolateral movement in walking is sometimes seen in AT lessons; it seems to arise through attention to postural conditions in the whole body, as opposed to focusing on transiently stabilizing leg joints.

Postural Tone Affects Movement and Balance. As the research on AT and tone indicates, changes in distribution and adaptivity of tone affect movement and balance. In the broadest sense, tone is a foundational system that affects other aspects of motor behavior via mechanical means (Gurfinkel, 2009; Ivanenko & Gurfinkel, 2018). As muscle tone underlies postural support, it exerts a general mechanical influence on movement and balance coordination by determining a "postural frame" for the body (Cacciatore et al., 2014). When tone is high and unmodulated, a body segment becomes stiff, hindering its motion.

The data on Alexander teachers rising from a chair compared with untrained controls indicate how more adaptive postural tone could help teachers solve the movement challenge of standing smoothly from a chair across a range of speeds. Alexander teachers' spines remained near isometric during weight shift, indicating that spinal torques were being closely counteracted during this period of changing axial forces (Cacciatore, Gurfinkel, Horak, & Day, 2011; Figure 2). However, their spinal stability when rising from a chair was unlikely to result from high spinal stiffness because teachers showed high compliance in Twister. Therefore, we can posit that AT teachers' near-isometric spines during weight shift resulted from dynamically matching the varying axial forces. In contrast, controls experienced greater changes in spinal alignment yet likely had higher stiffness in their hips and knees. A biomechanical model found that tone-related hip and knee stiffness could account for the inability of control subjects to smoothly rise from a chair by hindering the forward progression of the center of mass toward the feet (Cacciatore et al., 2014).

In the chair-rise task, Alexander teachers displayed similar differences compared with control subjects across the full range of

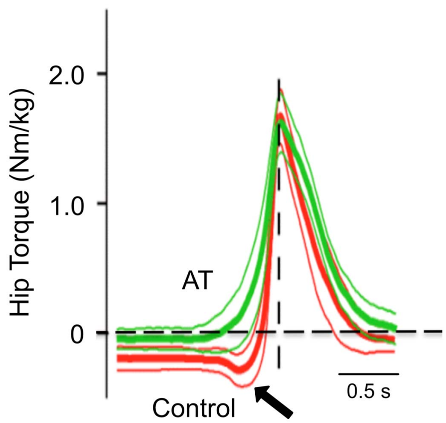

Figure 8 — Normalized hip torque during the 1-s chair rise in Alexander teachers and controls. Data from Cacciatore et al. (2014) as calculated from inverse dynamics. Positive indicates net extensor torque, negative indicates net flexor torque, and the dashed vertical line indicates seat-off. Mean and 95% CI for each group are shown. Note that only the control group used a hip-flexor torque at the start of the action to propel the trunk forward (black arrow). Alexander teachers avoided use of hip-flexor torque, suggesting that they used a force-matching strategy. AT = Alexander technique.

movement speeds, including an earlier and more gradual rise in foot force and a slower peak forward velocity. Interestingly, for the fastest movements (with an unattainable target speed), control subjects recruited hip flexors to speed up the movement by propelling their trunks forward, whereas Alexander teachers only displayed extensor moments (Figure 8). This suggests that even at high speeds, Alexander teachers still used a matching strategy rather than a preplanned movement strategy of flexing to move their body mass over their feet then extending to stand up (Cacciatore et al., 2014). In particular, the earlier and smoother rise of vertical foot force in Alexander teachers across all conditions (e.g., Figure 1) indicates they were closely opposing gravitational forces throughout the weight shift. Together, these findings suggest that Alexander teachers were solving the movement challenge of smoothly rising from a chair at different speeds by adaptive use of their postural system.

In general, the body axis requires ongoing postural support to coexist with motor action. Failure to adequately support the trunk with intrinsic muscles could lead to the recruitment of longer-range, more distal muscles for support, thereby interfering with limb movement through spreading (Loram et al., 2016). The results of Anderson and colleagues showing that Alexander teachers walk with reduced trunk motion but greater limb motion are consistent with the hypothesis that AT leads to improved deeper axial postural support, thereby preventing the spread of tension to limb muscles that would otherwise hinder leg-joint motion (Hamel et al., 2016). The improved step initiation from AT-inspired postural instructions is also consistent with improved action of the limbs through better axial postural support (Cohen et al., 2015).

Adaptability of postural tone may also affect balance. While one might think that increased stiffness would improve balance stability, the biomechanics of balance are complex (Latash, 2018), and in practice stiffness has been found to be detrimental. In healthy subjects, increased stiffness impairs both static and dynamic balance (Nagai, Okita, Ogaya, & Tsuboyama, 2017; Nagai et al., 2013; Warnica, Weaver, Prentice, & Laing, 2014; Yamagata, Falaki, & Latash, 2018). In patients with Parkinson's disease, high neck (Franzen et al., 2009) and hip stiffness (Wright, Gurfinkel, Nutt, Horak, & Cordo, 2007), as assessed by Twister, correlated with poorer balance and motor performance. This suggests that axial tone can affect balance-related activities, which are largely performed by the limbs. Note that balance could be compromised by failing to stabilize the spine from interaction torques caused by moving a limb. Thus, good balance may require precisely modulating axial tone to counteract such interaction torques.

Body Schema

Body schema is the set of internal representations of the body that the motor-control system relies on when planning and executing movement. In order to plan an action, the motor system integrates noisy sensory information from different sources into a coherent model of current body geometry (Gurfinkel, 1994; Head & Holmes, 1911; Medendorp & Heed, 2019). This model must also include the range of possible positions and movements. As body schema is used as a central reference for posture, movement planning, and execution, its accuracy, precision, and integration with the motor system are likely to have widespread motor effects (Haggard & Wolpert, 2005; Ivanenko et al., 2011).

Postural tone and body schema are similar in that both concern neurophysiological states rather than sequential processes like action and both are particularly suited to influence motor behavior in general (Gurfinkel, 2009; Ivanenko & Gurfinkel, 2018; Medendorp & Heed, 2019). Gurfinkel and colleagues proposed that tone and body schema work together to govern postural organization and provide a foundation for movement and balance (Gurfinkel, 1994; Gurfinkel, Ivanenko Yu, Levik Yu, & Babakova, 1995; Gurfinkel, Levick, Popov, Smetanin, & Shlikov, 1988).

Changes in body schema could also underlie changes in the adaptivity of tone. In the case of Twister, for example, if the trunk is represented as only one or two large blocks, the motor system will not have a sufficiently detailed model to interpret the subtle incoming sensory information and respond by precisely modulating the distribution of tone (Cacciatore, Gurfinkel, Horak, Cordo, & Ames, 2011; Cohen et al., 2015). Conversely, if the tone is rigid and undifferentiated so that the trunk moves as only one or two articulated blocks, this is likely to affect how the trunk is represented in the body schema (Gurfinkel, 1994).

One way of understanding body schema is by analogy to a detailed reference manual to the body that the motor system can access all or part of as needed. If, for whatever reason, the motor system fails to access the needed part of the reference manual, the output of the motor system will be less accurate (V.S. Gurfinkel, personal communication, 2003).

While there is no direct evidence that AT changes body schema, several anecdotal observations support its relevance to AT practice. For instance, AT lessons commonly use attention to the body and peripersonal space to influence tone, and it is common for pupils to report changes in perception of their body configuration during an AT lesson. When we describe protocols for assessing body schema to Alexander teachers (e.g., Parsons, 1987), there is widespread acknowledgment that these body-schema tasks resemble the type of spatial attention used in AT. (Over 100 teachers were surveyed informally during a series of workshops from 2016 to 2020.) Finally, chronic back and hand pain are associated with deficits in body schema, suggesting that improving it may be a component of AT pain reduction (Gilpin, Moseley, Stanton, & Newport, 2015; Moseley & Flor, 2012). The possible connections among body schema, postural tone, and motor control suggest an intriguing area of potential research on changes in body schema through AT instruction.

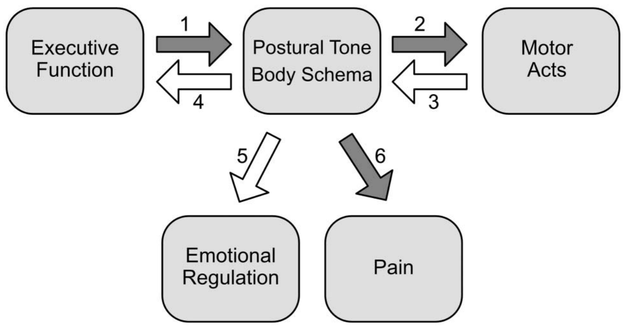

Figure 9 — Proposed model of AT. Postural tone and body schema form the hub of the model. Grey filled arrows indicate relationships that are corroborated through published data on AT. Open arrows indicate relationships supported by experiments not directly on AT. See text for explanation.

Model of AT Mechanisms

Our basic model is shown in Figure 9. In this section, we describe the model's block elements, followed by the numbered interactions between them. Postural tone (possibly in interaction with body schema) forms the central node in our model. In AT, spatial and body-schema phenomena are thought to be deeply interwoven with tone, as described herein. Changes in tone lead to changes in the perception of the structural organization of the body, and an improved body percept facilitates further improvements in tone (Loram, 2013; Loram 2015). Filled arrows indicate an evidence base that includes direct research on AT. Open arrows indicate an evidence base from relevant scientific fields, with future research needed to establish the relevance to AT.

We suggest that the body axis plays a central role in AT because of the critical function of postural tone in this region, due to the spine's instability and its central location, which require that axial tone mediate interactions between limbs. The deep spinal muscles may be particularly important because their shorter spans offer greater degrees of freedom when considered collectively to counter forces (Moseley et al., 2003). Deep spinal muscles also provide intrinsic support for the neck and trunk, in a way that gives a stable base for movement while minimizing the undesirable spreading of tension into the limbs. Thus, failure to adapt axial tone could lead to whole-body restrictions that could manifest as jerky, uncomfortable, or poorly controlled movement. Correcting this failure could have wide-ranging benefits. The neck may be especially crucial due to its proximal location at the top of spine and direct role in orienting the head (Loram et al., 2016).

The model proposes that postural tone interacts with executive processes, motor acts, emotional regulation, and pain.

Arrow 1

The first arrow in the model indicates the influence of executive function on postural tone in Alexander study and practice. This includes the processes of directing attention to postural tone and body schema, applying inhibitory control to motor planning and execution to prevent automatic patterns of muscle activation, and monitoring departures from postural intentions.

The AT process of "directing" involves applying specific intentions to postural tone, body schema, and spatial awareness. Changes in tone from AT-based instructions suggest that executive function can influence tone and body schema (Cohen et al., 2015, 2020). This process may be related to what movement scientists call kinesthetic motor imagery (Chiew, LaConte, & Graham, 2012), although such studies mostly examine the mental representation of overt movement rather than mental representations of desired postural states (c.f. Gildea, van den Hoorn, Hides, & Hodges, 2015).

The AT process of "inhibiting" may refer to the undoing or prevention of unnecessary tensing, whether at rest, in anticipation, or during an action. In a lesson, it may also refer to preventing the planning of an action, such as when rising from a chair using a matching strategy. The Alexander process of inhibiting may also refer to a more general intentional calming of the nervous system (see John Nicholls in Rootberg, 2018).

Arrow 2

The second arrow in the model indicates how motor behavior is influenced by postural tone and body schema. In general, tone affects mobility because excess stiffness interferes with joint motion and balance (Cacciatore et al., 2014; Warnica et al., 2014). Local stiffness may be important, but spreading may also be crucial; for example, poor support of the torso during a chair rise might cause excess leg tension that hinders forward motion of the torso. Counteracting external forces, particularly along the spine, allows some motor tasks to be performed quasistatically, such as rising from a chair or lifting a leg in dance. In addition, preventing undesirable preparatory tensing improves movement and balance (Cohen et al., 2015, 2020; Loram et al., 2016).

Body schema may directly affect movement (other than via influencing tone): Alterations in body schema affect the body reference used to plan action. For instance, Alexander teachers often help pupils perceptually understand the location of their hip joints, which facilitates leg-joint flexion, particularly in pupils who bend at the waist. In addition, pupils may avoid using joints or muscles with a history of pain or injury, leading to a reduction in the representation and functionality of these areas. Improving the body schema by bringing attention to these "lost" areas in relation to the whole-body organization may help previously disengaged areas become reengaged in movement.

Arrow 3

The third arrow in the model indicates the influence of motor behavior on postural tone. Chair work in AT, for instance, is not about learning to stand up with a particular movement trajectory. Performing movement tasks with particular constraints acts to inform and influence postural state. For instance, standing up with a smooth weight shift requires matching adaptation in extensor muscles of the back and legs, thereby acting to train the distribution and adaptivity of tone. The study from Loram and colleagues (Loram et al., 2016) provides another example of how a movement constraint can affect posture. Instructions and biofeedback to minimize neck tension while playing the violin led to changes in coordination that extended far beyond the neck to other regions playing postural roles.

Arrow 4

The fourth arrow in the model indicates the influence of postural tone on executive function. Evidence supporting this claim comes from a recent preliminary study that found improved performance in the Stroop task (a measure of inhibitory control) and increased backward digit span (a measure of working memory) after a series of AT classes (Gross, Ravichandra, Mello, & Cohen, 2019). Another study found performance on this same test of inhibitory control to be associated with habitual posture and executive function. Young adults with a habitual forward neck posture perform worse on the Stroop task and self-report lower levels of mindfulness than those with more neutral neck posture (Baer, Vasavada, & Cohen, 2019). While not conclusive, these findings suggest that skills used to learn AT may lead to improved executive function and awareness.

Arrow 5

The fifth arrow in the model indicates the influence of postural tone on emotion regulation. (Although emotional state is known to affect tone, this is a more general phenomenon, and we will not address it here.) There are several possible explanations for an effect of AT on emotional regulation. One possibility is that adaptable or reduced tension in the chest, abdomen, and back (without collapsing the body axis) leads to deeper, slower breaths, which downregulates a chronically overactive sympathetic nervous system (Breit, Kupferberg, Rogler, & Hasler, 2018; Jerath, Crawford, Barnes, & Harden, 2015). Another possibility is based on embodied cognition, which emphasizes that our experience of emotions relies on our interpretation of bodily sensations, including sensations of muscle tension. It is therefore plausible that activating postural patterns associated with being calm, alert, and confident will facilitate these feelings (James, 1894; Winkielman, Niedenthal, Wielgosz, Eelen, & Kavanagh, 2015; Osypiuk, Thompson, & Wayne, 2018). Finally, recent evidence indicates that axial motor regions, central to AT, may have a large influence in the regulation of the adrenal response to stress (Dum, Levinthal, & Strick, 2016).

Arrow 6

The sixth arrow in the model indicates the influence of postural tone on pain. Most of the clinical trials showing AT's effectiveness for pain have not examined mechanisms; the preliminary evidence to date points to postural tone as a potential cause of AT-related pain reduction. A small study found that a shift from surface to deep neck-muscle activity during a neck-flexion task after AT lessons was associated with a decrease in neck pain (Becker et al., 2018). Another intervention study found that decreased knee cocontraction during gait after AT lessons correlated with decreased knee pain in patients with knee osteoarthritis (Preece et al., 2016). Note that this study also demonstrated an absence of changes in pain-anticipatory brain activity, supporting the idea that postural tone underlies AT's reduction in pain rather than a central mechanism such as a general therapeutic effect.

Possible Underlying Neural Mechanisms

The phenomena involved in AT, such as postural tone, body schema, executive function, movement, balance, anticipatory tensing, matching, and spreading, almost certainly span a wide range of brain structures and processes. These can broadly be categorized into feed-forward and feedback influences on postural state (Figure 10). The neural substrates of some of these phenomena are themselves poorly understood—especially the core element of postural tone. With only two reports of measured neural activation associated with AT to date, it may seem premature to speculate about the neural underpinnings of AT (Preece et al., 2016; Williamson, Roberts, & Moorhouse, 2007). However, with this caveat in mind, we think it may be informative to relate our model to neural structures.

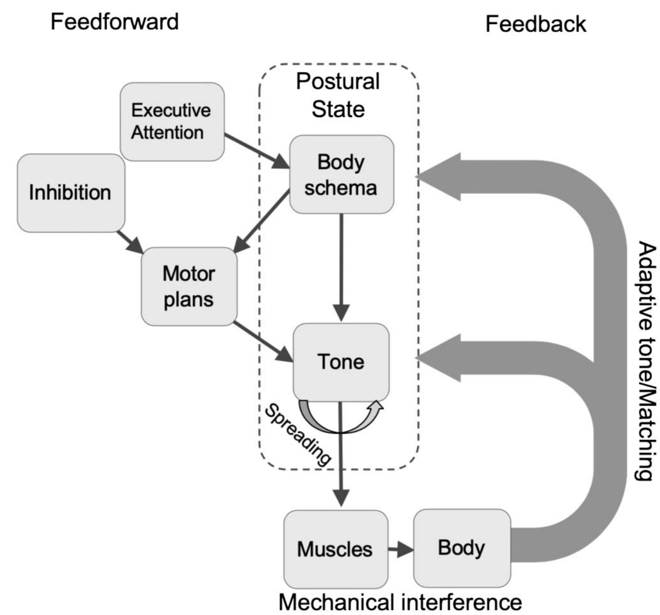

Figure 10 — Feed-forward and feedback influences on postural state relevant for the Alexander technique. Postural tone and body schema form the core of the model. The left side of the diagram shows feed-forward influences from executive attention, inhibition, and motor plans on postural tone and body schema. The right side shows feedback influences on postural state from sensory receptors. Adapting tone and matching forces must occur through feedback pathways. Spreading of tone is indicated centrally, but this may also occur through neuromechanical feedback pathways. See text for further explanation.

We think it likely that many aspects of AT affect tone-regulating (tonogenic) structures and related pathways. For instance, the influence of AT on adaptivity and distribution of tone via spatial attention might occur through frontoparietal pathways involving body schema that then project to tonogenic brain regions such as the brain stem. Executive processes might influence tone in feed-forward-planned actions via frontostriatal loops with involvement of cingulate cortex. Tone regulation to facilitate adaptivity and matching of forces could occur via feedback pathways through various brain levels and structures such as the brain stem, premotor cortex, and parietal cortex. It is also possible that sensorimotor brain rhythms are involved in shaping the tonic matching process. We start by briefly describing the neural regulation of postural tone and body schema and then consider how various brain pathways may affect these in the context of AT phenomena.

The Brain Stem and Central Regulation of Tone

Regulation of tone is poorly understood; modern explanations have moved away from a reflex-centered model to one that involves complex central regulation from the brain stem, basal ganglia, and other structures such as the vestibular nuclei and cerebellum (Davidoff, 1992). Neural integrators in the brain stem may be fundamental to generating the sustained activity for tone from more transient signals (Shaikh, Zee, Crawford, & Jinnah, 2016). The only brain-scan data available on AT, from a single-subject pilot study (Williamson et al., 2007), found activity in brain-stem regions that participate in tone regulation (Mori, Kawahara, Sakamoto, Aoki, & Tomiyama, 1982; Takakusaki, Chiba, Nozu, & Okumura, 2016). Thus, it is possible that AT influences tone through connections from higher attentional areas to brain-stem tonogenic regions. In general, axial body regions are subserved by different brain pathways than those controlling limbs, which may partially explain why axial tone is special in AT (Lawrence & Kuypers, 1968). While peripheral feedback loops undoubtedly contribute to tone generation, central regulation permits the learning of skills. The various aspects of postural tone, such as distribution, adaptivity, and spreading across the musculature, provide a complex palette with which AT may operate.

Conceptualizing tone as a state of readiness rather than a state of muscle tension may be relevant for understanding AT. Bernstein (1967) famously used an analogy of a musician pressing a string down on the neck of a violin as readiness, since this determines the note but does not produce a sound until it is bowed. This concept of tone as readiness may explain the body's ability to automatically resist or comply with external forces according to the tonic state prepared in advance. For instance, as Alexander teachers lean forward when preparing to rise from a chair, the precise matching of forces on their spines could be due to the configuration of tonic axial support and feedback loops before the action starts.

Sensorimotor Feedback Loops

Adapting tone to comply with external forces and adapting tone to match external forces both require incorporating sensory information via feedback loops. However, these two processes are fundamentally different in one respect: Compliance allows changes in the body's position, while matching forces keeps position the same—or allows slow changes with very low acceleration.

Compliant Adaptation. As compliant adaptation causes changes in body posture that persist after the applied forces are removed, the feedback loops for yielding must converge on the tonogenic brain areas to change the set point of tone. Compliant tone regulation occurs through lengthening and shortening reactions, which decreases activation when a muscle is lengthened and increases it when the muscle is shortened (Gurfinkel et al., 2006; Sherrington, 1909). While the pathways that produce this adaptation are not understood, the long latencies and variability of the process are consistent with cortical involvement (Miscio, Pisano, Del Conte, Colombo, & Schieppati, 2006). Compliance can be temporarily enhanced, such as through the Kohnstamm procedure (Gurfinkel et al., 2006). This childhood game of pressing one's arm outward against a wall for a minute then observing it float up effortlessly induces adaptable tone (Gurfinkel et al., 2006). Thus, AT may be engaging Kohnstamm-like processes that selectively upregulate specific brain-stem and spinal-cord circuits that contribute to motor behavior (Ivanenko et al., 2017).

Resistive Adaptation. In contrast to compliant adaptation, force matching in AT does not require a change to tonic set points and therefore may occur through other stabilization processes. Thus, while the increase in extensor activity during a chair rise may come from increased output of tonogenic structures, the increase in activity may also arise from other pathways such as those that require the intention to not let the body deform. Feedback loops through the parietal cortex, primary motor cortex, or cerebellum might be involved.

Although tonic activity is relatively rare in motor cortex (Shalit, Zinger, Joshua, & Prut, 2012), it is possible that the cortex participates via sensorimotor rhythms. Some sensorimotor rhythms couple cortical activity to muscles, to sensitively facilitate brain–muscle communication (Oya, Takei, & Seki, 2020). Enhanced sensorimotor rhythms contribute to tonic activation of muscles during voluntary maintenance of a position (Kilavik, Zaepffel, Brovelli, MacKay, & Riehle, 2013). While this muscle activation does not meet the definition of postural tone, as it depends on a voluntary intention, it may be relevant to the matching process we have described in AT lessons.

Stabilization also occurs by feed-forward mechanisms when the brain can predict forces in advance. Such feed-forward mechanisms are relevant to the preparatory activity that occurs before an action takes place, such as pulling the head forward before walking (Baer et al., 2019). In addition, preparing to tap a finger causes anticipatory stabilization all the way up the arm into the back before the finger movement is even made, because activating finger muscles without proximal stabilization would lead to unwanted changes in wrist and arm angles (Caronni & Cavallari, 2009).

Frontoparietal Circuitry, Inhibition, and Body Schema

Abundant research has demonstrated the importance of the parietal cortex, including the temporal parietal junction, for body schema (Di Vita, Boccia, Palermo, & Guariglia, 2016). The parietal cortex is also involved in the representation of space around the body and is activated by body-related words (Iriki, Tanaka, & Iwamura, 1996; Rueschemeyer, Pfeiffer, & Bekkering, 2010). Thus, attending to spatial relationships of the body or peripersonal space, as in AT "directing," may engage the frontoparietal network, including body-schema regions.

The parietal cortex also participates in other functions that may be relevant to AT. For instance, it is involved in both global motor inhibition and the motor inhibition of selective body regions (Desmurget et al., 2018; Kolodny, Mevorach, & Shalev, 2017). This parietal function may be relevant to the "embodied" inhibition Alexander teachers describe, as it incorporates spatial attention and body awareness. In contrast, executive inhibition is not typically described as relating to bodily attention (Aron, 2011). The parietal cortex also contributes to the sense of agency, the perception that one controls one's actions (Glover et al., 2018).

Recent research has shown that pain alters the somatotopic mapping in sensory and motor cortices. For instance, cortical representations of the neck are altered in people with recurring neck pain (Elgueta-Cancino, Marinovic, Jull, & Hodges, 2019). Moreover, repetitive sensory experiences can disrupt sensory processing over time, causing distorted neural representations of the body. This can lead to focal hand dystonia (Byl & Melnick, 1997; Loram, 2015). Addressing body representations appears to have a positive effect on pain (Moseley & Flor, 2012). This may involve correcting neural representations of the body (Loram, 2015).

Frontostriatal Circuitry, Beta Rhythms, and Motor Plans

Action plans such as those used to kick a ball, type on a keyboard, or open a door are generated in the motor cortex, supplementary motor area, and basal ganglia through frontostriatal loops. This circuitry is involved in the initial assembly of a motor plan from subcomponents and in selecting, launching, halting, or preventing execution of plans. The basal ganglia also influence muscle tone via connections to the brain stem (Martin, 1967; Takakusaki et al., 2016). Thus, this circuitry may contribute to the triggering of undesirable changes in tone, such as the preparatory tension a professor might experience when approaching a podium to lecture. It follows that the same circuitry would be involved in redressing problems with tone, especially when the tone is associated with a motor plan.

Brain rhythms in the basal ganglia and sensorimotor cortex may contribute to inhibition of action plans in contexts where matching forces is a more appropriate response. Beta rhythms (13–30 Hz) are thought to sustain static posture, preventing the launch of motor plans (Kilavik et al., 2013; Solis-Escalante et al., 2019). Thus, upregulating beta rhythm may inhibit the launch of a movement plan, facilitating the use of a matching strategy.

Support for the idea that AT engages frontostriatal circuitry comes from observations that people with Parkinson's disease (a neurodegenerative disease affecting basal ganglia along with other brain areas) have particular deficits in regulating postural tone, executive function, movement planning/preparation, and body schema (Amboni, Cozzolino, Longo, Picillo, & Barone, 2008; Cohen, Horak, & Nutt, 2012; Moustafa et al., 2016)—all functions apparently addressed by AT. Evidence indicates that AT is helpful for people with Parkinson's disease, which suggests that AT may target regions such as the frontostriatal circuitry that are disrupted in Parkinson's (Gross, Ravichandra, & Cohen, 2019; Stallibrass, Sissons, & Chalmers, 2002).

Prefrontal Cortex, Cingulate Cortex, and Executive Function

Because AT lessons engage with pupils' goals and ask pupils to make decisions, brain areas associated with executive function are almost certainly involved. Multiple subregions of the prefrontal cortex are associated with goal setting, decision making, and proactive inhibitory control (Aron, 2011). In addition, the cingulate cortex is involved in monitoring the environment for deviations from intended outcomes and activating corrective responses (Pearson, Heilbronner, Barack, Hayden, & Platt, 2011).

Speculation on the Nature of Hands-On Instruction in AT

Although AT can be taught without manual contact, a particular form of hand contact is cultivated in AT teacher training, and one-to-one lessons usually include some touch. This can be as simple as a teacher putting a hand on a particular part of the pupil's body (e.g., rib cage or upper back) to bring the pupil's attention there. However, most pupils agree that there is something "special" about the hands-on work of an Alexander teacher beyond just the choice of where to make contact. Ideally, the postural tone of an Alexander teacher is adaptively distributed from the axial motor system out to the limbs, so that the hands do not "grab," or "push"; nor are they "relaxed." From a mechanical perspective, this may give a sort of springiness. A skilled teacher can intentionally combine resistance and compliance in a sophisticated way that facilitates the organization of the pupil's tone. To the student, the hands are perceived as supportive and guiding even when the actual contact force is very light. A similar quality of manual contact has been observed in expert ballroom dancers and practitioners of the "soft" martial arts such as Tai Chi and Aikido.

Anecdotal evidence from teachers' experience suggests that body schema may partially underlie AT hand contact. It appears that teachers expand their body schema through this contact to include the body configuration and muscle tensions of the pupil. This may be related to the well-established phenomenon by which primates expand their body schemas and sense of peripersonal space to incorporate tools (Iriki et al., 1996). We speculate that Alexander teachers' extensive experience enables them to incorporate the complex kinetic structure of a human form into their body schema, in order to understand and communicate tensional patterns and bodily awareness (Soliman, Ferguson, Dexheimer, & Glenberg, 2015).

Discussion

Model Strengths

Our model is broad and ambitious, with the goal of explaining as many AT-related phenomena as possible while attempting to remain relatively simple. Our model explains effects seen in a wide variety of AT research studies, including reduced lateral motion during gait, smoother rise from a chair, reduced activity in surface neck muscles, longer neck and spine, greater compliance to slow rotation of the body axis, steadier balance, and improved automatic postural coordination. It accommodates a large range of teaching styles including verbal instructions, hands-on work, traditional procedures, and activity work. It explains why the skills learned in AT generalize to so many different activities including those that are not directly addressed in an AT lesson. It explains why the work focuses on the body axis and does not address body parts in isolation and why and how AT's focus on the body axis is distinct from popular models that focus on "core support." By showing how body schema and tone are deeply intertwined, it may reconcile differing perspectives about the role of sensory feedback in AT. The model describes how the engagement of the body schema may contribute to the increased sense of agency often described after lessons. We also present an outline of a plausible neural model that awaits further elaboration and testing.

Model Limitations

The largest limitation we encountered in developing this model is the paucity of published data to constrain it. We have therefore relied in part on anecdotal observations from Alexander practice, such as for the incorporation of body schema. Moreover, there may be multiple different body schemas that may extend beyond the parietal cortex (Ivanenko et al., 2011; Medendorp & Heed, 2019). In addition, the section on neural mechanisms is based on almost no direct data of what brain regions are active during the practice of AT. The most well-established tool for brain imaging is magnetic resonance imaging, which requires subjects to lie down; this complicates the study of postural phenomena.

Our model does not address every relevant question, such as why postural tone is not optimal in the first place or how the AT learning process occurs over time. Both of these topics have been explored by Loram and colleagues (Loram, 2013; Loram, 2015) by treating motor selection and sensory processing as part of a feedback loop that becomes unstable for postural phenomena. This may be relevant for understanding the process of learning AT. Finally, there are no data on how touch is used in AT, so our discussion on AT touch is supposition.

Conclusion

We have argued for a model of AT that is centered on postural tone and body schema, with changes in motor behavior, emotional regulation, and pain mostly downstream from those central changes. We have supported this model with research findings where possible. As more basic-science progress is made, the model will evolve.

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